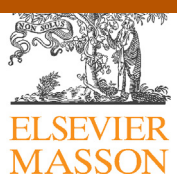
European Annals of Otorhinolaryngology, Head and Neck diseases (2013) 130, 321—325



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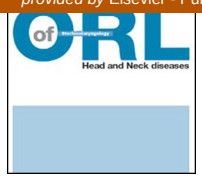

ORIGINAL ARTICLE

Ultrasound analysis of the upper esophageal sphincter during swallowing in the healthy subject

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KEYWORDS
Neck ultrasound;
Sonography;
Swallowing;
Upper esophageal sphincter

Summary
Objectives: The purpose of this study was to develop a methodology and standard settings for ultrasound study of the upper esophageal sphincter (UES) during swallowing.
Material and methods: This was a prospective study of 25 healthy volunteers (15 women and 10 men) aged 20 to 56 years. Neck ultrasonography was performed as each volunteer swallowed 10 mL of water three times. The parameters studied were: diameter of the closed UES; diameter of the open UES; anterior and lateral displacement (measured in cm) of the UES as the water bolus flowed through it; duration of UES opening; and average duration of UES displacement (measured in ms). Student's *t* tests for paired and unpaired samples were applied for the statistical analysis.
Results: The mean diameter of the closed UES was 0.78 ± 0.13 cm, while the mean duration of opening was 415 ± 57.66 ms and the mean duration of displacement was 937 ± 120.98 ms. Maximum anterior and lateral displacement of the UES was 0.42 ± 0.12 cm and 0.35 ± 0.18 cm, respectively. There was a significant difference between men and women for lateral displacement of the UES ($P = 0.04$).
Conclusion: This study established standards for ultrasound study of the UES during swallowing, using a non-invasive readily accessible method that may be useful for assessing swallowing disorders involving the UES (Zenker's diverticulum, fibrosis, stricture).

Introduction

Swallowing is a complex phenomenon by which a food bolus is propelled from the oral cavity into the stomach. It requires the coordination of 25 pairs of muscles in the oral cavity, pharynx, larynx and esophagus. Thus, swallowing constitutes one of the most elaborated functions of the human body [1]. Three phases can be distinguished: the oral phase;

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http://dx.doi.org/10.1016/j.anorl.2012.01.008

the pharyngeal phase; and the esophageal phase. The upper esophageal sphincter (UES) plays an essential role in swallowing, marking the transition from the pharyngeal phase to the esophageal phase. Correct function of the UES is therefore indispensable for an effective swallowing process. The UES is situated 15 cm below the dental arch and measures 2 to 4 cm in length. It is defined as a zone of high pressure separating the pharynx from the esophagus, and is composed of three adjacent muscles: the inferior esophageal constrictor; the cricopharyngeus (the predominant muscle); and the muscularis mucosae of the cervical portion of the esophagus. The largest portion of the inferior esophageal constrictor is inserted on the thyroid cartilage. Its innervation arises from the pharyngeal plexus and a branch of the recurrent nerve. The cricopharyngeus, a striated muscle mainly composed of slow type 1 fibers, but also with a few rapid fibers allowing early adaptation to certain situations, corresponds to the lower portion of the inferior pharyngeal constrictor. It contains an abundant amount of connective tissue, making it highly elastic. Its motor innervation arises mainly from the recurrent nerve, while its sensory innervation is from the glossopharyngeal and superior laryngeal nerves. The only circular muscle fibers are found in the muscularis, the motor innervation of which arises from the tenth cranial nerves.

The UES opens when muscle relaxation is associated with a forward and upward movement of the cricoid cartilage, which is raised 2 to 3 cm. This allows the bolus to flow across the UES during swallowing or vomiting. Closure of the UES prevents the intake of air [2]. Several pathological conditions (Zenker's diverticulum, neurological disorders including Parkinson's disease, post-radiation stricture) can affect the UES, leading to major swallowing disorders [3—5].

Videofluorography is considered the gold standard for UES study during swallowing, but this is an invasive method that also exposes the subject to radiation [6]. Fiberoptic endoscopy has been proposed as a routine minimally effective method for assessing UES function [7]. Endoluminal sonography [8] and manometry can be used to explore the UES, but both require insertion of a probe that, in certain conditions, can alter bolus flow. Other methods such as high-resolution manometry [9], electromyography [10] and kinetic magnetic resonance imaging (MRI) [11] are currently under evaluation in specialized centers. However, conventional ultrasonography (US) has not been used for routine assessment of swallowing despite its availability and non-invasive nature.

The purpose of our present study was to describe study of the UES by US during swallowing in a population of normal subjects to evaluate its feasibility, and to compare results by gender as well as with data in the literature obtained by other methods.

Material and methods

This study was approved by the local ethics committee (Comité de Protection des Personnes de Tours-Ouest 1).

Subjects

This was a prospective study conducted with 25 healthy adults (15 women and 10 men) aged 20 to 56 years. Inclusion criteria were: age 18 to 70 years; no known disease affecting swallowing; and written informed consent to participate. Exclusion criteria were: presence of disease affecting swallowing; history of surgery or radiotherapy involving the upper airways; neurological disease (such as multiple sclerosis and Parkinson's disease); psychiatric disorder; gastrointestinal disease (such as gastroesophageal reflux and hiatal hernia); and otorhinolaryngological disease (such as Zenker's diverticulum and laryngeal palsy) affecting swallowing.

Methods

Recording protocol

US studies were performed with a MyLab™ 70 XVision system (Esaote Group, Genova, Italy) and a Biosound LA523 thyroid probe set at 7 MHz. With the subject in a sitting position, the probe was placed on the left side of the neck to obtain an axial view along the lower border of the cricoid cartilage, identified by palpation and US imaging. The upper pole of the thyroid gland was also used as a landmark. The UES was recognized by its specific C-shaped anatomical structure attached to the cricoid cartilage (Fig. 1) [8].

Subjects were instructed to swallow in one go 10 mL of room-temperature water delivered with a syringe. Three recordings were made for each subject with a lapse of at least 30 s between recordings. The bolus was prepared in the syringe, which was then placed in the subject's mouth before swallowing as instructed by the operator. The US data were stored on a mobile USB storage device before being transferred to a computer for processing.

Signal processing was performed with a 'visualization' program, developed by the University of Tours School of Engineering (http://polytech.univ-tours.fr), that enables US image processing at a speed of 25 images/s. Distances were measured with Photoshop®.

Morphological measurements

These measurements (Figs. 1 and 2) included: outer cross-sectional diameter of the closed UES, measured in

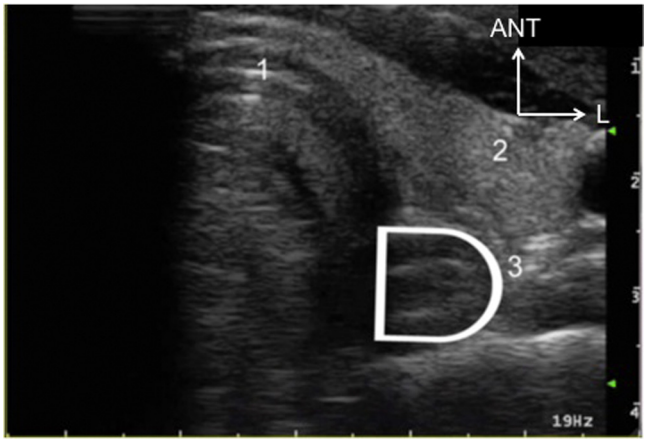

Figure 1 Ultrasonography of the closed upper esophageal sphincter: 1: cricoid cartilage; 2: left thyroid lobe; and 3: the closed upper esophageal sphincter, which is C-shaped and attached to the cricoid cartilage.

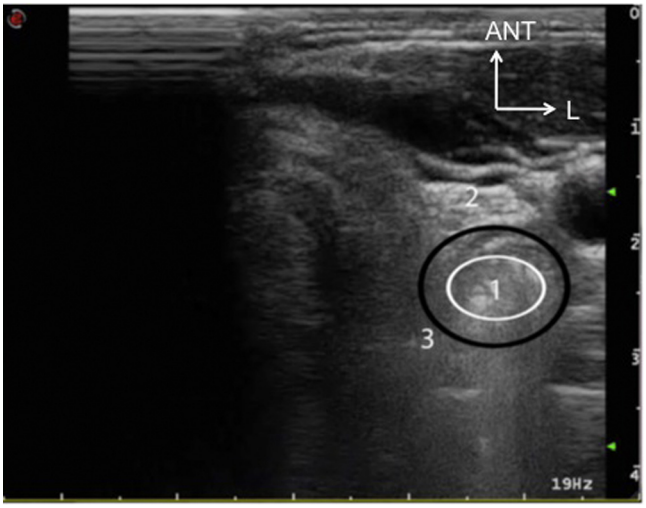

Figure 2 Ultrasonography of the upper esophageal sphincter as the bolus crosses the sphincter: 1: inner contour of the open upper esophageal sphincter; 2: left thyroid lobe; and 3: outer contour of the open upper esophageal sphincter.

centimeters (cm) from the cricoid insertion to the outermost edge; outer cross-sectional diameter of the open UES, including lumen and musculature; inner cross-sectional diameter of the open UES, considered to also correspond to the maximum bolus diameter; thickness of the UES musculature in the open position, determined by subtracting the inner cross-sectional diameter from the outer cross-sectional diameter of the open UES; and anterior and lateral displacement of the UES using the centimeter scales on the sides and bottom of the US images. The center of the UES served as the reference point.

Functional measurements

These data were recorded in milliseconds (ms) and included: duration of UES displacement, corresponding to the time interval between the first perceived movement of the UES and its final resting position; duration of the bolus flow through the sphincter, considered equivalent to the duration of UES opening; time interval between the onset of UES displacement and its opening; and time interval between UES closure and its final resting position.

Statistical analysis

Student's *t* test was applied to all variables for comparisons between men and women, while Student's *t* test for paired samples was applied to compare the time interval between the onset of UES displacement and its opening with the time interval between closure of the UES and its final resting position. Maximum anterior and lateral displacement of the UES during swallowing, as well as the thickness of the UES musculature in closed and open positions, were compared using the same test.

Results

Population

Twenty-five subjects participated in this study (15 women and 10 men) and provided 75 US recordings. Mean age was 30 years 11 months ± 10 years 9 months (31 years 7 months ± 12 years 9 months for women and 29 years 10 months ± 7 years 3 months for men); the difference was not significant ($P = 0.66$). Mean body weight was 61.2 ± 9.78 kg (55.2 ± 5.97 kg for women and 70.2 ± 7.04 kg for men), and mean height was 169.1 ± 10.23 cm (162.9 ± 6.89 cm for women and 178.4 ± 6.77 cm for men); body weight and height were significantly different between men and women ($P < 0.0001$ for both tests).

Morphological measurements

The mean cross-sectional diameter of the closed UES was 0.78 ± 0.13 cm, while the mean inner cross-sectional diameter of the open UES was 0.954 ± 0.15 cm and the mean outer cross-sectional diameter of the open UES was 1.413 ± 0.16 cm (Table 1).

The mean thickness of the musculature of the open UES was 0.457 ± 0.16 cm (0.490 ± 0.13 cm for women and 0.408 ± 0.19 cm for men). This was significantly less than the thickness of the musculature of the closed UES ($P < 0.001$).

Mean maximum anterior and lateral displacement of the UES during swallowing was 0.42 ± 0.12 cm and 0.35 ± 0.18 cm, respectively. Lateral displacement was significantly greater in men than in women ($P = 0.04$; Table 2).

Functional measurements

The mean duration of UES opening was 415 ± 51.66 ms and the mean duration of UES displacement was 937 ± 120.98 ms. Mean time from the onset of UES displacement to its opening was 330.1 ± 80.26 ms, while the mean time from UES closure to its return to resting position was 188.7 ± 72.15 ms (Table 3). The mean time from the onset of UES displacement to its opening was significantly longer than the mean time from closure of the UES to its return to resting position ($P < 0.0001$).

Discussion

The present study was a dynamic US examination combined with data processing to provide perfect visualization of the UES in healthy subjects as a water bolus flowed across it. All of the recordings were suitable for analysis, thus demonstrating the reliability of this reproducible and well-tolerated method.

Image acquisition

A learning curve was evident on applying this new technique. Trial and error was necessary to determine the best probe and most appropriate settings. The LA523 probe set at 7 MHz proved to be the optimal choice.

Table 1 Ultrasound measurement of the upper esophageal sphincter (UES).

Mean diameter	Total population	Men	Women	*P*
Closed UES (cm)	0.78 ± 0.13	0.83 ± 0.13	0.74 ± 0.12	0.08
Open UES: inner diameter (cm)	0.95 ± 0.15	1.02 ± 0.17	0.91 ± 0.12	0.12
Open UES: outer diameter (cm)	1.41 ± 0.16	1.43 ± 0.17	1.40 ± 0.16	0.75

Table 2 Mean anterior and lateral displacement of the upper esophageal sphincter (UES) as the bolus flows across the sphincter.

Displacement	Total population	Men	Women	*P*
Anterior (cm)	0.42 ± 0.12	0.46 ± 0.12	0.40 ± 0.12	0.07
Lateral (cm)	0.35 ± 0.18	0.44 ± 0.15	0.29 ± 0.18	0.04

Protocol

The study sample size of 25 subjects was determined by biostatisticians at the Tours University Hospital Center. Although the number of men and women differed (15 women versus 10 men), because the total number of subjects was sufficient, this did not hinder any statistical comparisons. Also, the lack of any statistical differences between genders in terms of age and body mass index allowed the conclusion that they were comparable. Mean age of the study subjects was 30 years 11 months ± 10 years 9 months. This was therefore a young population that could not be stratified for comparisons by age. The bolus volume was 10 mL, chosen because this was often used in the literature for the assessment of swallowing, particularly in videofluorography and manometry studies [12,13]. Water was chosen for the 'food' bolus to ensure good compliance, and three recordings were made for each subject as swallowing exhibits interindividual and intraindividual variability [14]. This allowed a mean to be established for each subject, while avoiding extreme values that might have hampered the analysis.

Morphological measurements

The diameter of the closed UES in our study was 0.78 ± 0.13 cm, larger than that obtained by endoluminal US (0.55 ± 0.12 cm) [8]. This may be explained by the approximation of a circular UES whereas, in reality, the UES is C-shaped and attached to the cricoid cartilage. It may also be explained by the level at which the UES was measured. The cricoid was used as the landmark in our study whereas, with endoluminal US, measurements were taken at the level of the highest manometric pressure reading.

The inner diameter of the open UES observed in the present study (1.02 ± 0.17 cm) was smaller than that reported in a videofluorographic study (2.1 ± 3.7 cm) using barium swallows, which are thicker than water [6]. This might be an explanation, as Kahrilas [15] found that the diameter of the open UES increases with increasing bolus consistency. In addition, Cook et al. [6] measured the cross-sectional diameter at the upper portion of the UES whereas, in the present study, the UES opening was visualized at its lower portion. This point has another consequence. Unlike earlier reports [8], the present study demonstrated a thicker musculature for open versus closed sphincters. This could be explained by the 2 to 3 cm upward movement of the UES during swallowing. In the present study protocol, the US probe was held stationary during both muscle-thickness measurements (open and closed UES), and the open measurement was probably made in the lower portion of the UES, known to have a thinner muscle layer [8]. Thus, the upward movement of the UES should be taken into account when interpreting US measurements.

In addition, to our knowledge, the anterolateral displacement of the UES during swallowing has not been previously described in the literature. Yet, this displacement was considerable, measuring 0.42 ± 0.12 cm for the anterior movement and 0.35 ± 0.18 cm for the lateral movement. Indeed, it might be useful to measure this parameter in pathological settings, as it is probably related to tissue elasticity. This means that events causing fibrosis (radiation therapy, surgery) may also affect this parameter. Such a study using US is currently being conducted in different pathological contexts.

Table 3 Functional ultrasound measurements of the upper esophageal sphincter (UES).

	Total population	Men	Women	*P*
Opening duration (ms)	415 ± 58	406.5 ± 47	420.6 ± 47	0.54
Displacement duration (ms)	937 ± 121	962.3 ± 152	920.2 ± 97	0.45
Time from beginning of displacement to opening (ms)	330.1 ± 80	346.1 ± 109	319.5 ± 55	0.49
Time from closure to return to resting position (ms)	188.7 ± 72	201.6 ± 70	180.1 ± 75	0.47

Functional measurements

The mean duration of bolus flow across the UES measured in our present study (415 ± 57.66 ms) was comparable to that measured for 10-mL water swallows with high-resolution manometry (450 ± 13 ms) by Ghosh et al. [12]. The mean time from the onset of UES displacement to its opening was in agreement with results obtained with videofluorography recordings of swallowing [13]. In fact, UES displacement can be considered equivalent to the laryngeal displacement observed with videofluorography, as the UES is attached to the cricoid, causing its movement to make an equivalent movement of the UES. The same is true for the mean time from closure of the UES to its return to resting position. However, these two time intervals were significantly different. This may be explained by the kinetics of cricoid cartilage movement: it moves upwards before the UES opens and then moves anteriorly, thereby triggering opening of the UES, attached posteriorly to the prevertebral fascia [2]. The descending phase occurs more directly, with no time lag, making its duration shorter.

The present study has provided no assessment of the overall duration of the swallowing process in the upper esophagus. It has, however, demonstrated that UES displacement lasts around 1 s (937 ± 120.98 ms), which is close to the laryngeal displacement observed with videofluorography [13].

Conclusion

The present study has presented a non-invasive method using a standard protocol for US assessment of the UES during swallowing. Neck US was also found to be a reliable, reproducible and well-tolerated method that allows dynamic acquisition of morphological and functional measurements as the bolus flows across the UES. In addition, US allowed the description and measurement of the anterolateral displacement of the UES during swallowing. These findings in healthy subjects can now serve as baseline values for US study of the UES in pathological contexts, which will be the topic of our next study.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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